



Star Formation in Las Campanas Compact Groups

Sahar S. Allam¹

National Research Institute for Astronomy & Geophysics, Helwan, Cairo, Egypt;
shr@frcu.eun.eg, sallam@fnal.gov

Douglas L. Tucker

Fermi National Accelerator Laboratory, MS 127, P.O. Box 500, Batavia, IL 60510, USA;
dtucker@fnal.gov

Huan Lin²

Steward Observatory, University of Arizona, 933 N. Cherry Ave. Tucson, AZ 85721, USA;
hlin@as.arizona.edu

and

Yasuhiro Hashimoto³

Carnegie Observatories, 813 Santa Barbara Street, Pasadena, CA 91101, USA;
hashimot@vorp.al.ciw.edu

ABSTRACT

Compact groups (CGs) of galaxies offer an exceptional laboratory for the study of dense galaxian environments — where interactions, tidally induced activity, and mergers are expected to be at their highest rate of occurrence. Here, we present first results from a new catalogue of compact groups, one based upon the Las Campanas Redshift Survey (LCRS). Using the equivalent width of [O II] $\lambda 3727$, we have studied the star formation activity in LCRS CGs: we find strong evidence of *depressed star formation* in CGs relative to that in loose groups or the field. Although much of this effect can be ascribed to morphological mix (CGs contain a high fraction of early-type galaxies), there is some evidence that the star formation rate in late-type galaxies is particularly deficient — perhaps only one-half to one-third that of field spirals. We conclude that gas stripping mechanisms may play a role in CG environments.

Subject headings: catalogs – galaxies: clusters: general – galaxies: interactions – galaxies: starburst

¹Visiting Scientist, Fermi National Accelerator Laboratory

²Hubble Fellow

³Also: Dept. of Astronomy, Yale University, New Haven, CT 06520-8101; hashimot@astro.yale.edu

1. Introduction

Perhaps over half of all galaxies lie within groups containing 3–20 members (Tully 1987); yet, due to the difficulty of discerning them from the field, groups of galaxies are, as a whole, not as well studied as larger galaxy systems. Compact groups (CGs), however, defined by their small number of members (< 10), their compactness (typical intra-group separations of a galaxy diameter or less), and their relative isolation (intra-group separations \ll group-field separations) are more readily identifiable.

Recently, Tucker et al. (1999) produced a catalogue of loose groups (LGs) from the Las Campanas Redshift Survey (LCRS; Shectman et al. 1996), using an adaptive friends-of-friends algorithm (Ramella et al. 1989). Intrigued by the work of Barton et al. (1996), who created a CG catalogue from the Center for Astrophysics (CfA) Redshift Survey and found that most of their CGs were embedded in dense environments, we produced a similar catalogue from the much deeper LCRS (Allam & Tucker 1998, Tucker et al. 1999). For extracting group catalogues, redshift surveys have an advantage over sky surveys since redshift adds a third dimension of constraint: group catalogues based upon redshift surveys tend to have far fewer chance alignments than do those based upon sky surveys (e.g., Hickson 1982, 1993; HCG). We apply a standard friends-of-friends algorithm to extract a sample of CGs systems in the LCRS. Our definition for these CGs is as follows:

- ≥ 3 galaxies,
- compact (projected nearest-neighbor inter-galaxy separations of $D_L \leq 50h^{-1}\text{kpc}$, or ~ 1 galaxy diameter), and
- isolated in redshift (nearest-neighbor inter-galaxy velocity differences $V_L \leq 1000 \text{ km s}^{-1}$).

The LCRS, optimized for efficient observing with a fiber-fed multi-object spectrograph, has a 55 arcsec fiber separation limit. This has prevented the observation of spectra for all galaxies which were members of close pairs; so, many galaxies in CG environments are missing from the LCRS redshift catalogue. We have partially circumvented this problem by assigning each of the $\sim 1,000$ “missing” LCRS galaxies the redshift of its nearest neighbor and convolving it with a gaussian of $\sigma=200 \text{ km s}^{-1}$, a value which is similar to the typical median velocity disperion of HCGs (Hickson 1982) and of LCRS LGs (Tucker et al. 1999); hence, on the small angular scales necessary for compact group selection, the LCRS falls somewhere between a 2D sky survey and a fully 3D redshift survey. The resulting catalogue contains 76 CGs having 3 or more members, and evidence for interactions in many of these CGs (in the form of tidal tails, bridges, etc.; see Allam & Tucker 1998, Allam et al. 1999) confirms that they are indeed, for the most part, physical systems. All the CGs contain at

least one redshift; 23 contain 2 or more. (Unfortunately, only one LCRS CG has redshifts for all its members.) The innate physical properties of LCRS CGs — such as typical group richnesses and densities — are similar to those of the Barton et al. catalogue, which in turn are similar to those of the HCG catalogue, especially for CGs with 4 or more members. The median redshift for LCRS CGs, however, is ~ 0.08 , more than twice that of either of the other two CG catalogues. As with the HCG and Barton et al. samples, LCRS CGs represent some of the densest concentrations of galaxies known and thus provide ideal laboratories for studying the effect of strong interaction on the morphology and stellar content of galaxies. Details of the general properties of these CGs and of how they were extracted from the LCRS will be discussed in Allam et al. (1999); here, we will focus on the star formation properties in LCRS CG environments.

It is well known that direct interactions between galaxies tend to increase their star formation rate (SFR) (Larson & Tinsley 1978; Bushouse 1987; Kennicutt et al. 1987). LCRS CGs represent an environment where interactions, tidally triggered activity, and galaxy mergers are expected to be at their highest rate of occurrence. Therefore, if no other factors dominate, we may expect a global enhancement in the SFR of LCRS CG galaxies. In order to test this hypothesis, we will use the equivalent width (EW) of the $[\text{O II}] \lambda 3727$ emission line (Colless et al. 1990, Kennicutt 1992) as a star formation indicator.

The paper is organized as follows: § 2 describes the sample under investigation, § 3 discusses the sample’s spectroscopic properties, and § 4 relates the sample’s morphological features; finally, in § 5, we summarize our main conclusions.

2. The Samples

As a first step towards the clarification of the effect of high density environments on enhancing the SFR in galaxies, it is necessary to characterize the SFR of galaxies in more isolated environments. For that reason, a sample of 253 CG galaxies, a sample of 7621 LG galaxies, and a sample of 13452 field galaxies have been selected from the LCRS. Particular care was taken in order to obtain a loose group sample in which no galaxies from CGs were included. Further, galaxies from both LGs and CGs were excluded from the field sample. Our goal is to study environmental factors affecting the SFR of galaxies by taking advantage of the very large and homogeneous data set available from the LCRS.

Before we move on, however, a concern must be addressed: could the fiber separation effect — the fact that, in high-density regions, the fraction of LCRS galaxies with spectra is lower than that in low-density regions — bias our analysis? To first order, this concern

is unimportant, since we are comparing the fraction of starbursts (see § 3) against the total sample of galaxies with spectra — not against the total sample of galaxies both with and without spectra. Furthermore, the galaxies removed due to the fiber size were removed blindly — i.e. with no regard to their star formation properties or morphological type. On the other hand, uncertainties in group membership due to the fiber separation effect can obscure the boundary between low- and high-density regimes, possibly diluting the differences in the observed properties of these environments. In other words, any environmental effects we detect would likely be even stronger in an uncontaminated sample.

3. Distribution of [O II] Equivalent Widths

Several works have used $\text{EW}(\text{O II } \lambda 3727)$ as a star formation index for distant galaxies (Colless et al. 1990, Kennicutt 1992). We have used automatically measured rest-frame LCRS $\text{EW}(\text{O II})$'s, which have a mean error of 2.2 \AA [Hashimoto et al. (1998)]. Figure 1 shows the distribution of the $\text{EW}(\text{O II})$ of LCRS galaxies in CGs, in LGs, and in the field. A formal χ^2 test indicates that the distribution for CGs differs from that for LGs at the 99.99965% confidence level, and from that for field galaxies at the 99.99951% confidence level. (These very high formal confidence levels are due partly to the large samples involved and partly to the large differences among these samples for the smallest bin.)

Following Hashimoto et al. (1998), we classify the emission line strength as follows: NEM (no emission), for which $\text{EW} < 5 \text{ \AA}$; WEM (weak emission), for which $5 \text{ \AA} \leq \text{EW} < 20 \text{ \AA}$; and SEM (strong emission), for which $\text{EW} \geq 20 \text{ \AA}$. The WEM class contains mostly normal galaxies, where star formation is governed by internal factors such as gas content and disk kinematics. The SEM class contains mainly starburst galaxies, where star formation is due to interaction. Table 1 represents the frequency of $\text{EW}(\text{O II})$ for galaxies in different environments. The variations in the frequency of the SEM class may reflect environmental variations in galaxy-galaxy interaction rates.

Note that the fraction of LG galaxies showing a normal (WEM) SFR is only three-quarters that for the field galaxies, and the fraction of LG galaxies showing starburst (SEM) activity is only two-thirds that in the field. For CG galaxies, the ratios are more severe: the fraction of CG galaxies with normal SFR is only two-thirds that for the field galaxies, and the fraction of CG galaxies which are star-bursting is only half that of the field, indicating that the SFR in high density environments is generally weaker than in the field.

4. The Concentration Index C of LCRS galaxies

Although the SFR in high density environments is, on average, depressed relative to that than in the field, much of this effect might be due merely to differences in average morphological mix. After all, spirals, which are more prevalent in the field, tend to have higher average SFRs than do ellipticals. To test this possibility, we have made use of Hashimoto et al. (1998)’s measurement of the concentration index, C , for LCRS galaxies as a measure of the morphological types of the galaxies in our sample. The C index represents the intensity-weighted second moment of a galaxy; it compares the flux between specified inner and outer isophotes of a galaxy to indicate the degree of light concentration. As such, the C index is related to the Hubble type (Abraham et al. 1994), where late/irregular type galaxies have smaller C values. The total number of galaxies in our sample with a measured C index is 12901. The mean and median C index is given for each of the different galaxy environments in Table 2.

The C distribution of CGs galaxies is shown in Figs. 2 & 3. A KS test indicates that the CG galaxies are drawn from the same morphological parent population as the LG galaxies at a probability of 20%; the probability that CG and the field galaxies have the same morphological mix is only 0.2%. Clearly, the distribution of CG galaxies is skewed toward early types (large C ’s).

In Fig. 4, the distribution of EW(O II) vs. C index is shown for LCRS galaxies in the different environments. The relation between the mean C index, $\langle C \rangle$, and the mean EW(O II), $\langle \text{EW(O II)} \rangle$, is presented in Fig. 5. Note that $\langle \text{EW(O II)} \rangle$ increases smoothly with decreasing $\langle C \rangle$ for LG and field galaxies, parallelling the relation between Hubble type and EW(O II) (Kennicutt 1992). Although much noisier, the same relation holds basically true for CG galaxies, too. We must note, however, that the latest-type (the smallest C bin) CG galaxies show a significant deficit of star formation — perhaps only one-half to one-third that of field galaxies of this morphology. Therefore, it appears that not all the differences between the average star formation properties of CGs, LGs, and the field are due merely to morphological mix. Some appear to be due to the dampening of star formation within late-type CG galaxies.

5. Conclusion

The star formation histories of galaxies in CGs can provide insight into the environmental factors that influence the evolution of galaxies. One approach is to examine the spectra of galaxies for evidence of ongoing star formation or of a young stellar

population. We can then compare the fraction of compact group galaxies with recent star formation with the fraction from loose groups and the field.

We have done this by making use of a new catalogue of CGs, based upon the LCRS, which contains 253 galaxies in 76 CGs. To clarify whether interaction produces enhanced star formation in LCRS CGs, they have been compared to carefully selected samples of LCRS LG and field galaxies. In all, a sample of 21326 LCRS galaxies in the three different environments was employed.

We compared the SFR based on the strength of the emission line $\text{EW}(\text{O II})$ for LCRS CGs, LGs, and field galaxies: we found that the fraction of starbursts for CG members is roughly half that for the field, whereas for LG galaxies it is roughly two-thirds that for the field. Also we found that a normal galaxy SFR occurs for LCRS CG galaxies at roughly two-thirds the rate for the field, whereas for LG galaxies this rate is three-fourths that for the field. This means that, on average, the star formation in high density environments is depressed with respect to the field.

Much of this effect can be attributed to the different morphological mixes associated with low and high density environments: when we compared the distribution of the concentration index C of galaxies in CGs, in LGs, and in the field, we found the distribution of CGs galaxies to be definitely skewed towards early morphological types (large C index), which generally tend to have relatively low SFRs. Nonetheless, when we then compared the SFR vs. the C index for CG, for LG, and for field galaxies, we found that the SFR for CGs appears to be deficient for very late morphological types (small C index) — in fact, the SFR for these late-type CG galaxies is only one-half to one-third the SFR for field spirals.

It is clear from these findings that CG environments tend to depress star formation, partly due to a relative overabundance of early-type galaxies and partly due to some mechanism that dampens star formation within late-type CG spirals. Note that results from other sources — in particular, the HCG catalogue and from Zabludoff & Mulchaey’s (1998) sample of poor groups — lend support to this view. For example, both of these other samples have been shown to have galaxy populations skewed toward early types (Hickson 1982, Zabludoff & Mulchaey 1998). More interesting, however, is the growing body of evidence, both in the far-infrared (Allam 1998) and in $\text{H}\alpha$ (Iglesias-Páramo & Vílchez 1999), that the global star formation rates within HCGs are, on average, not enhanced relative to field samples of similar morphological mix. Indeed, Iglesias-Páramo & Vílchez even note a marginally significant locus of HCG spiral galaxies of particularly low $\text{H}\alpha$ emission in their Fig. 4; these HCG spirals may correspond to our LCRS CG sample of low-SFR late-type galaxies.

Therefore, our initial hypothesis — that interaction-induced starbursts dominate the global SFR in LCRS CGs — fails. Although starbursts are no doubt important, other factors prevail to yield a net depression in the SFR in CG environments. Much of this effect is merely due to the high fraction of early-type galaxies in CGs, but at least some of it is likely due to dampened activity in late-type galaxies; this second mechanism indicates that gas stripping mechanisms may play a role in CG environments.

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Table 1. The $EW(O\ II)$ of LCRS galaxies in different environments

Galaxies		$EW(O\ II)^a$					
Environment	Total No.	<i>NEM</i> $EW < 5\ \text{\AA}$		<i>WEM</i> $5\text{\AA} \leq EW < 20\ \text{\AA}$		<i>SEM</i> $EW \geq 20\ \text{\AA}$	
Compact Group	104	72	$(69.2\% \pm 8.2\%)$	27	$(26.0\% \pm 5.0\%)$	5	$(4.8\% \pm 2.2\%)$
Loose Group	6612	4312	$(65.2\% \pm 1.0\%)$	1892	$(28.6\% \pm 0.7\%)$	408	$(6.2\% \pm 0.3\%)$
Field	12915	6804	$(52.7\% \pm 0.6\%)$	4905	$(38.0\% \pm 0.5\%)$	1206	$(9.3\% \pm 0.3\%)$

^aThe equivalent widths (EW) are classified as no emission (NEM; $EW < 5\ \text{\AA}$), weak emission (WEM; $5\text{\AA} \leq EW < 20\ \text{\AA}$), and strong emission (SEM; $EW \geq 20\ \text{\AA}$).

Table 2. The Concentration Index C of LCRS galaxies.

Galaxies Environment	Total No.	mean	median
Compact Group	86	0.324 ± 0.009	0.302
Loose Group	4528	0.303 ± 0.001	0.298
Field	8287	0.287 ± 0.008	0.28

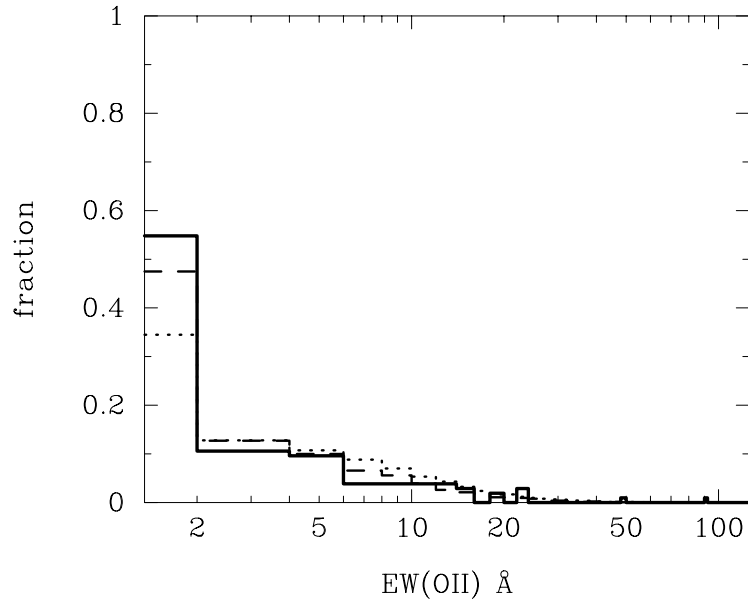


Fig. 1.— The distribution of the equivalent widths (EW) of [O II] $\lambda 3727$ of LCRS galaxies in compact groups (full line), loose groups (dashed line), and the field (dotted line). A formal χ^2 test indicates that the distribution for compact groups differs from that for loose groups at the 99.99965% confidence level, and from that for field galaxies at the 99.99951% confidence level.

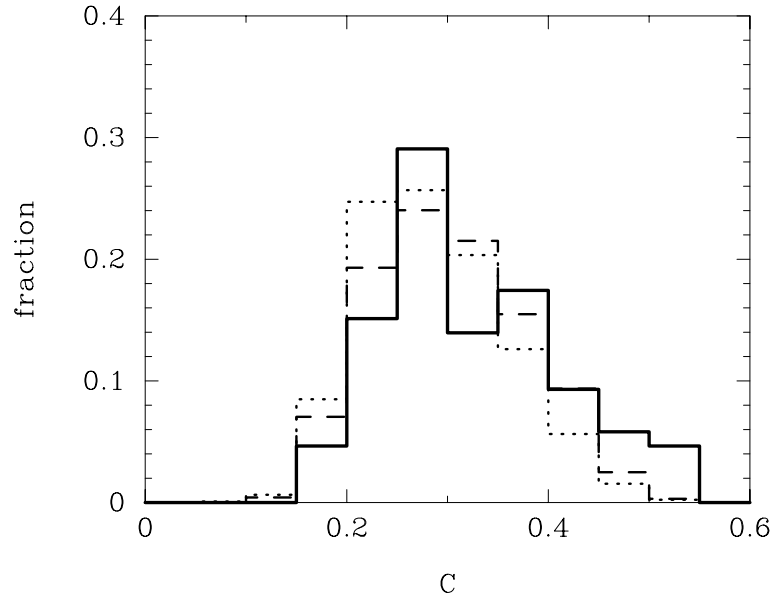


Fig. 2.— Distribution of the concentration index C of LCRS compact group galaxies (full line), loose group galaxies (dashed line), and field galaxies (dotted line).

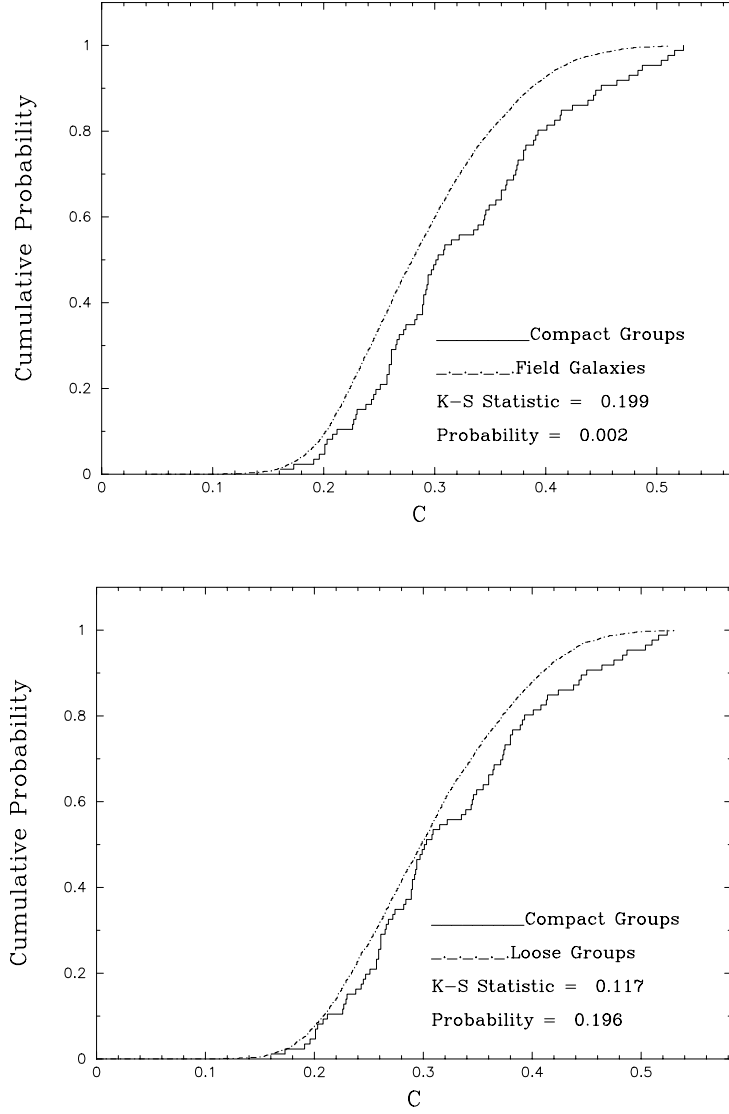


Fig. 3.— The cumulative distribution of the concentration index C of the LCRS compact group galaxies vs. field galaxies (top), and compact group galaxies vs. the loose group galaxies (bottom). The C distribution of LCRS compact group galaxies is skewed toward early type (large C).

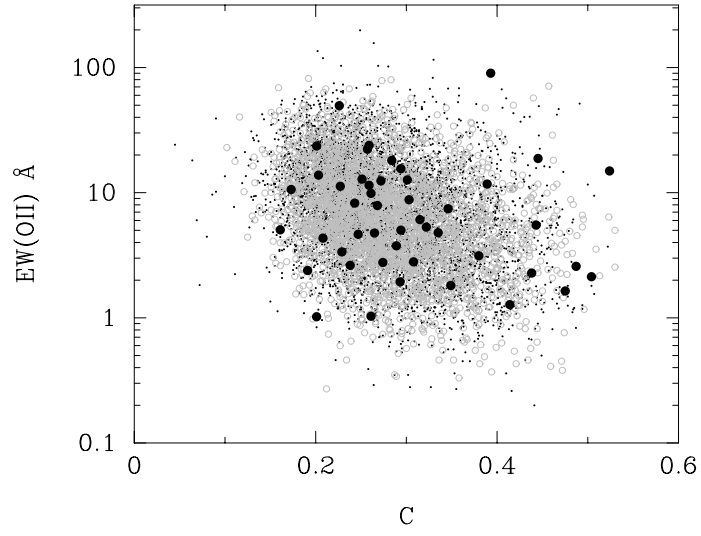


Fig. 4.— $EW(O II) \lambda 3727$ vs. C index for LCRS galaxies in compact groups (filled circles), in loose groups (unfilled circles), and in the field (points).

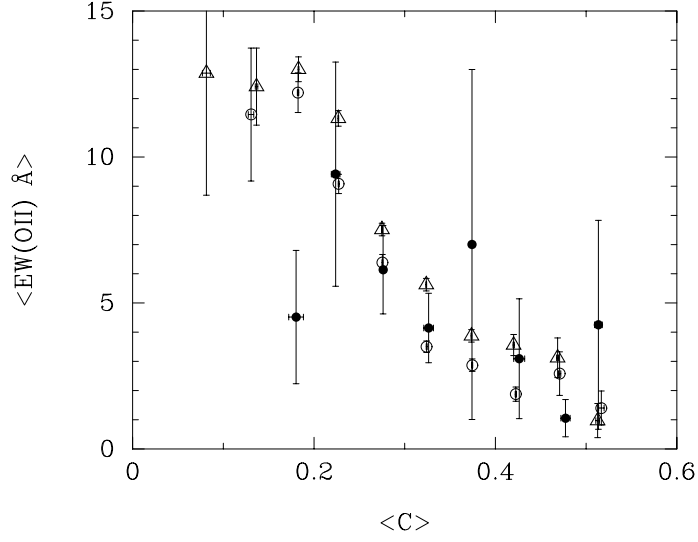


Fig. 5.— The relation between the mean concentration index, $\langle C \rangle$, and the mean $\text{EW}(\text{O II})$, $\langle \text{EW}(\text{O II}) \rangle$, for compact group galaxies (filled circles), for loose group galaxies (open circles), and for field galaxies (open triangles).